

**THEREFORE WHAT IS CLAIMED IS:**

**1. A wavelength tunable composite material, comprising:**

an ordered array of first constituents having a first refractive index embedded within a cross-linked metallopolymer network having a second refractive index different than the first refractive index, the ordered array of first constituents having a lattice spacing giving rise to Bragg diffraction when the composite material is illuminated,

the cross-linked metallopolymer network being comprised of a polymer backbone including metal atoms chemically integrated therein, the cross-linked metallopolymer network having an electronic configuration dependant on the metal atoms, the metal atoms being switchable between more than one electronic configuration, the cross-linked metallopolymer network being expandable and contractible in response to controlled uptake and expulsion, respectively, of a selected fluid by the cross-linked metallopolymer network so that when the cross-linked metallopolymer network takes up the selected fluid it expands which shifts a Bragg diffraction wavelength to longer wavelengths and when the cross-linked metallopolymer network expels the selected fluid it contracts which shifts the Bragg diffraction wavelength to shorter wavelengths, the amount of fluid uptake and expulsion being controlled by controlling the electronic configuration of the cross-linked metallopolymer network.

2. A wavelength tunable composite material according to claim 1 wherein the cross-linked metallopolymer network contains metal atoms selected from the group consisting of titanium, vanadium, chromium, manganese, iron, cobalt, nickel, copper, niobium, molybdenum, ruthenium, rhenium, platinum, palladium, and rhodium, zinc, and combinations thereof.

3. A wavelength tunable composite material according to claim 1 wherein the metal atoms chemically integrated into the polymer backbone are connected together directly or through linking units or combinations thereof.

4. A wavelength tunable composite material according to claim 3 wherein the linking units are selected to impart pre-selected chemical, physical, electrochemical, optical and electronic properties to the cross-linked metallopolymer network.

5. A wavelength tunable composite material according to claim 3 wherein the cross-linked metallopolymer network has segments in which the metal atoms are connected directly to each other to impart pre-selected chemical, physical, electrochemical, optical and electronic properties to the cross-linked polymer network.

6. A wavelength tunable composite material according to claim 4 wherein the linking units are selected from the group consisting of substituted or

unsubstituted carbanions, conjugated carbanions, linear olefins, cyclic olefins, acetylenes, phosphines, amines, carbonyls, carbenes, alkoxides or combinations thereof.

7. A wavelength tunable composite material according to claim 3 wherein the metal atoms chemically integrated into the polymer backbone bear side-chain ligands which are selected from the group consisting of substituted or unsubstituted carbanions, conjugated carbanions, linear olefins, cyclic olefins, acetylenes, phosphines, amines, carbonyls, carbenes, alkoxides or combinations thereof.

8. A wavelength tunable composite material according to claim 3 wherein the cross-links in the metallopolymer network is one of chemical bonds, physical bonds, nanoparticles, surfaces, hydrogen bonds, coordination bonds, electrostatic interactions, hydrophobic interactions, fluorophobic interactions and phase-separated domains or combinations thereof.

9. A wavelength tunable composite material according to claim 3 wherein the cross-links in the cross-linked metallopolymer network are electronically conducting or electronically insulating.

10. A wavelength tunable composite material according to claim 1 wherein the cross-linked metallopolymer network has a preselected number density and distribution of crosslinks throughout the composite material.

11. A wavelength tunable composite material according to claim 1 wherein the cross-linked metallopolymer network is formed from the polymerisation of a metal-containing monomer selected from the group consisting of bridged metallocenophanes.

12. A wavelength tunable composite material according to claim 11 wherein the bridged metallocenophanes are substituted sila-1-ferrocenophanes.

13. A wavelength tunable composite material according to claim 12 wherein the substituted sila-1-ferrocenophanes are selected from the group consisting of dialkylsila-1-ferrocenophanes, alkylalkoxysila-1-ferrocenophanes, dialkoxysila-1-ferrocenophanes, cycloalkylsila-1-ferrocenophanes, diarylsila-1-ferrocenophanes, alkylarylsila-1-ferrocenophanes, alkylalkenylsila-1-ferrocenophanes, alkylalkynylsila-1-ferrocenophanes or combinations thereof, and a metal-containing crosslinker selected from the group consisting of cyclobutylsila-1-ferrocenophane, sila-1,1'-diferochenophane, 1,2-*bis*(methylsila-[1]-ferrocenophane)acetylene, 1,4-*bis*(methylsila-[1]-ferrocenophane)benzene, *bis*(methylsila-[1]-ferrocenophane)-1,4-diethynylbenzene, and 1,2- *bis*(methylsila-[1]-ferrocenophane)ethane or combinations thereof.

14. A wavelength tunable composite material according to claim 1 wherein the cross-linked metallopolymer network is formed from the polymerisation of a mixture of compounds including about 50-100 weight % monomer, 0-30 weight % crosslinker, and 0-20 weight % initiator.

15. A wavelength tunable composite material according to claim 1 wherein the cross-linked metallopolymer network is a polymer selected from the group of polyferrocenylsilanes.

16. A wavelength tunable composite material according to claim 1 wherein the cross-linked metallopolymer network has a pre-selected porosity.

17. A wavelength tunable composite material according to claim 1 wherein the first constituents include microparticles selected from the group of spheres, ellipsoids, rods, sphere containing polyhedra, cubes, and polyhedra, having cross-sectional dimensions from about 60 nanometers to about 100 micrometers.

18. A wavelength tunable composite material according to claim 1 wherein the first constituents include substantially monodisperse microspheres having diameters from about 60 nanometers to about 100 micrometers.

19. A wavelength tunable composite material according to claim 1 wherein the first constituents include substantially monodisperse microspheres selected from

the group consisting of insulators, polymers, metals, and semiconductors or combinations thereof.

20. A wavelength tunable composite material according to claim 1 wherein the first constituents include substantially monodisperse microspheres made of silica.

21. A wavelength tunable composite material according to claim 1 wherein the first constituents include substantially monodisperse microspheres selected from the group consisting of polystyrene and polymethylmethacrylate.

22. A wavelength tunable composite material according to claim 10 wherein the first constituents are voids filled with a pre-selected gas of a predetermined pressure.

23. A wavelength tunable composite material according to claim 1 wherein the first constituents are formed as a thin film in the form of a predetermined pattern on a substrate selected from the group consisting of metals, insulators, semiconductors, semimetals, polymers, and liquids or combinations thereof.

24. A wavelength tunable composite material according to claim 1 wherein the first constituents are formed as a free-standing monolith structure.

25. A wavelength tunable composite material according to claim 17 wherein the first constituents are assembled into a crystal having a pre-selected three-dimensional shape.

26. A wavelength tunable composite material according to claim 25 wherein the crystal is single-crystalline or poly-crystalline.

27. A wavelength tunable composite material according to claim 1 wherein the first constituents are modified to increase the adhesion between the first constituents and the cross-linked polymer network.

28. A wavelength tunable composite material according to claim 1 wherein the substrate is modified to increase the adhesion between the substrate and the cross-linked metallopolymer network as well as to increase the adhesion between the first constituents closest to the substrate with the substrate and the cross-linked polymer network.

29. A wavelength tunable composite material according to claim 1 wherein the first constituents form a face-centered cubic (fcc) arrangement in the composite material.

30. A method of wavelength tuning a composite material, comprising:

a) producing an ordered array of first constituents having a first refractive index embedded within a cross-linked metallopolymer network having a second refractive index different than the first refractive index, the ordered array of first constituents having a lattice spacing giving rise to Bragg diffraction when the composite material is illuminated, the cross-linked metallopolymer network being comprised of a polymer backbone including metal atoms chemically integrated into the polymer backbone and connected together directly or through linking units, the cross-linked polymer network having an electronic configuration dependant on the metal atoms, the metal atoms being switchable between more than one electronic configuration, the cross-linked metallopolymer network being expandable and contractible in response to controlled uptake and expulsion, respectively, of a selected fluid by the cross-linked metallopolymer network so that when the cross-linked polymer network takes up the selected fluid it expands which shifts a Bragg diffraction wavelength to longer wavelengths and when the cross-linked polymer network expels the selected fluid it contracts which shifts the Bragg diffraction wavelength to shorter wavelengths, the amount of fluid uptake and expulsion being controlled by controlling the electronic configuration of the cross-linked polymer network; and

b) switching the electronic configuration of the cross-linked metallopolymer network so that the cross-linked polymer network changes dimensions and modulates the lattice spacing of the ordered array of first constituents, which shifts the Bragg diffraction wavelength to a pre-selected wavelength.



31. A method according to claim 30 wherein the step of switching the electronic configuration of the cross-linked metallopolymer network is performed on a localized spatial area of the cross-linked polymer network.

32. A method according to claim 30 wherein the step of switching the electronic configuration of the cross-linked metallopolymer network includes switching a given proportion of the metal atoms to a predetermined oxidation state.

33. A method according to claim 32 where the oxidation state of the given proportion of the metal atoms is switched by the application of a pre-selected stimulus.

34. A method according to claim 33 wherein the stimulus includes exposing the composite material to a substance which is an oxidizing agent and switches the oxidation state of a given proportion of the metal atoms to a higher oxidation state.

35. A method according to claim 34 wherein the oxidizing agent is selected from the group consisting of transition metal complexes, main group compounds, radicals, radical cations and combinations thereof.

36. A method according to claim 33 wherein the stimulus includes exposing the composite material to a substance which is an reducing agent and switches the oxidation state of a given proportion of the metal atoms to a lower oxidation state.

37. A method according to claim 36 wherein the reducing agent is selected from the group consisting of transition metal complexes, main group compounds, alkali metals, alkali earth metals, radicals, radical anions and combinations thereof.

38. A method according to claim 33 wherein the stimulus includes exposing the composite material to electromagnetic radiation.

39. A method according to claim 33 wherein the stimulus includes exposing the composite material to electromagnetic radiation in the presence of a substance which upon exposure to the electromagnetic radiation becomes an oxidizing agent or reducing agent.

40. A method according to claim 33 wherein the stimulus includes exposing the composite material to electromagnetic radiation which creates a temporary change in oxidation state of a given proportion of the metal atoms within the cross-linked metallopolymer network.

41. A method according to claim 33 wherein the stimulus includes exposing the composite material to a change in temperature.

42. A method according to claim 33 wherein the stimulus includes exposing the composite material to a change in temperature in the presence of a substance which upon exposure to the change in temperature becomes an oxidizing agent or reducing agent.

43. A method according to claim 33 wherein the stimulus includes exposing the composite material to a change in temperature which creates a temporary change in oxidation state of a given proportion of the metal atoms within the cross-linked metallopolymer network.

44. A method according to claim 33 wherein the stimulus includes exposing the composite material to an electric field.

45. A method according to claim 44 wherein the electric field causes an increase in the oxidation state of a given proportion of the metal atoms within the cross-linked metallopolymer network.

46. A method according to claim 44 wherein the electric field causes a decrease in the oxidation state of a given proportion of the metal atoms within the cross-linked metallopolymer network.

47. A method according to claim 44 wherein the electric field causes a redistribution in the oxidation states or charge distribution of a given proportion of the metal atoms within the cross-linked metallopolymer network.

48. A method according to claim 30 wherein the fluid is a gas of controlled static pressure.

49. A method according to claim 30 wherein the fluid is a gas, the composite material being exposed to a controlled flow of the gas.

50. A method according to claim 30 wherein the fluid is a liquid of controlled static pressure.

51. A method according to claim 30 wherein the fluid is a liquid, the composite material being exposed to a controlled flow of the liquid.

52. The wavelength tunable composite material produced according to claim 1 produced according to a method comprising the steps of:

a) forming an ordered array of the first constituents, which displays Bragg diffraction, in a cross-linked metallopolymer network precursor mixture,

b) inducing cross-linking of the cross-linked metallopolymer network precursor mixture and converting it to a cross-linked metallopolymer network with a given number density of cross-links.

53. The wavelength tunable composite material produced according to claim 52 wherein step a) includes organizing the first constituents into an ordered array which displays Bragg diffraction, and then infiltrating the cross-linked metallopolymer network precursor mixture into void spaces between the first constituents.

54. The wavelength tunable composite material produced according to claim 52 wherein step a) includes organizing the first constituents into an ordered array in the presence of the cross-linked metallopolymer network precursor mixture.

55. The wavelength tunable composite material produced according to claim 52 including modifying the surface of the first constituents in a manner suitable to increase the adhesion between the first constituents and the cross-linked metallopolymer network.

56. The wavelength tunable composite material produced according to claim 52 including modifying the surface of the first constituents and the substrate in a manner suitable to increase the adhesion between the first constituents and the cross-linked metallopolymer network as well as to increase adhesion between the first constituents closest to the substrate with the substrate and the cross-linked metallopolymer network.

57. The wavelength tunable composite material produced according to claim 53 wherein the cross-linked metallopolymer network precursor mixture is a liquid which is infiltrated into void spaces between the first constituents.

58. The wavelength tunable composite material produced according to claim 53 wherein the cross-linked metallopolymer network precursor mixture is a solid which is heated and infiltrated into void spaces between the first constituents as a liquid melt.

59. The wavelength tunable composite material produced according to claim 53 wherein the cross-linked metallopolymer network precursor mixture is a solid which is infiltrated into void spaces between the first constituents by sublimation.

60. The wavelength tunable composite material produced according to claim 53 wherein the cross-linked metallopolymer network precursor mixture is a solid which is infiltrated into void spaces as a solution in a liquid.

61. The wavelength tunable composite material produced according to claim 53 wherein the cross-linked metallopolymer network precursor mixture is a gas which forms the cross-linked metallopolymer network by a surface reaction on the surface of the first constituents.

62. The wavelength tunable composite material produced according to claim 53 including controlling the amount and distribution of cross-linked metallopolymer network precursor mixture in void spaces of the first constituents.

63. The wavelength tunable composite material produced according to claim 53 wherein a top surface of the array of first constituents is overcoated by the cross-linked metallopolymer network precursor mixture by a thickness of 0 nm to 100 nm.

64. The wavelength tunable composite material produced according to claim 63 where the overcoat is limited to a cross-sectional dimension of the first constituent particles by pressing a substrate against the array of first constituents infiltrated with the cross-linked metallopolymer network precursor mixture, squeezing out any excess which is not in the spaces between the first constituents.

65. The wavelength tunable composite material produced according to claim 63 where the substrate is made of an elastomeric material.

66. The wavelength tunable composite material produced according to claim 52 wherein step b) includes cross-linking of the cross-linked metallopolymer network precursor mixture using a controlled amount of polymerisation initiator incorporated into the cross-linked metallopolymer network precursor mixture.

67. The wavelength tunable composite material produced according to claim 66 wherein the polymerisation initiator causes cross-linking of the cross-linked metallopolymer network precursor mixture by a stimulus selected from time, change in temperature, electromagnetic radiation, chemical reaction, electrochemical reaction and combinations thereof.

68. The wavelength tunable composite material produced according to claim 52 wherein step b) includes cross-linking of the cross-linked metallopolymer network precursor mixture by a stimulus selected from time, change in temperature, electromagnetic radiation, chemical reaction, electrochemical reaction and combinations thereof.

69. The wavelength tunable composite material produced according to claim 52 wherein the cross-linked metallopolymer network precursor mixture includes a pre-selected amount of an additive which is removed after cross-linking resulting in a cross-linked metallopolymer network of pre-selected porosity.

70. The wavelength tunable composite material produced according to claim 52 wherein step b) includes cross-linking of the cross-linked metallopolymer network precursor mixture to give a pre-selected number density and distribution of crosslinks throughout the composite material.



71. The wavelength tunable composite material produced according to claim 52 wherein additives are incorporated into the cross-linked metallopolymer network following cross-linking.

72. The wavelength tunable composite material produced according to claim 64A wherein the additives are chosen to modify the properties of the cross-linked metallopolymer network.

73. The wavelength tunable composite material produced according to claim 72 wherein the additives are selected from the group consisting of solvents, solutions, gases, solids, dyes, molecules, metal nanoclusters, semiconductor nanoclusters, macromolecules, molecule assemblies, as well as particles selected from the group of spheres, ellipsoids, rods, sphere containing polyhedra, cubes, and polyhedra, having cross-sectional dimensions from about 0.1 nanometers to about 1 micrometer.

74. The wavelength tunable composite material produced according to claim 52 wherein the ordered array of first constituents is produced as a thin film of controlled area and thickness on a pre-selected substrate.

75. The wavelength tunable composite material produced according to claim 52 wherein the ordered array of first constituents is produced as a patterned thin film of controlled area and thickness on a pre-selected substrate.

76. The wavelength tunable composite material produced according to claim 52 wherein the ordered array of first constituents is produced as a shape of any pre-selected dimension or array of shapes of any pre-selected dimension on a pre-selected substrate.

77. The wavelength tunable composite material produced according to claim 76 where the substrate is selected from the group consisting of metals, insulators, semiconductors, semimetals, polymers, and liquids.

78. The wavelength tunable composite material produced according to claim 76 including modifying the surface of the substrate in a manner suitable to increase the adhesion between the substrate and the cross-linked polymer network.

79. The wavelength tunable composite material produced according to claim 52 wherein step b) includes controlling the given number density of cross-links by the controlled cleavage of a predetermined number of bonds in the cross-linked metallopolymer network.

80. The wavelength tunable composite material produced according to claim 79 wherein the controlled cleavage is performed by electrochemically cycling between more than one predetermined electronic configuration of the cross-linked metallopolymer network.

81. The wavelength tunable composite material produced according to claim 52 wherein after step b) of inducing cross-linking of the cross-linked metallopolymer network precursor mixture and converting it to a cross-linked polymer network with a given number density of cross-links is complete, including a step of removing the first constituents from the composite material to produce an inverted structure comprised of a periodic array of voids having substantially the shape of the first constituent particles and the cross-linked metallopolymer network.

82. The wavelength tunable composite material produced according to claim 52 wherein the substrate is one of as indium tin oxide, fluorine tin oxide, silicon and silica, metallic surfaces such as aluminium or chemically treated gold, polyphenylenevinylene, polymethylmethacrylate and mylar.

83. A wavelength tunable composite material according to claim 1 wherein the first constituents are substantially monodisperse microspheres made of silica and etched by aqueous hydrofluoric acid.

84. A wavelength tunable composite material according to claim 1 wherein the first constituents are substantially monodisperse microspheres made of polystyrene and etched with toluene or tetrahydrofuran.

85. A wavelength tunable composite material according to claim 1 wherein the first constituents are substantially monodisperse microspheres made of polyalkylmethacrylate and etched with acetone or tetrahydrofuran.

86. A wavelength tunable composite material according to claim 1 wherein the substrate which is conductive or insulating, optically transparent or reflective or opaque.

87. A wavelength tunable composite material according to claim 1 formed on a substrate in a plurality of regions with each region having a pre-selected area, each of the regions defining a display pixel, including means for stimulating each pixel independent of all the other pixels.

88. The wavelength tunable composite material produced according to claim 53 wherein the cross-linked metallopolymer network precursor mixture is one of a liquid and a solid dissolved in solution and the cross-linked metallopolymer network precursor mixture electrodeposited by using an oxidative potential or a reducing potential, where the application of the controlled potential causes a change in solubility in the cross-linked metallopolymer network precursor mixture and results in a solid being deposited in the void spaces of the first constituents.